Vicor DC-DC converter sensitivity to 150 MeV protons

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Objectives of the test

This test was made to evaluate the sensitivity of the nominal 300 VDC input Vicor DC-DC converter to single event effects (SEE) - single event gate rupture and single event burn-out.

Test conditions

The total integrated fluence of neutrons to which the converters will be subject under the operating conditions is $1.3 \times 10^{11}\ n \cdot cm^{-2}$. This number includes neutrons with kinetic energy from $2\ MeV$ to $1.5\ GeV$. In order to determine the SEE sensitivity we replaced the neutrons by protons assuming that both cause similar effects. For failure rate determination we assume that SEE has no particle kinetic energy dependence.

Experimental Setup

Measurements were performed at the Harvard Cyclotron Laboratory. Samples were irradiated with protons of of 150 MeV (148 MeV on the sample). The beam spot is in first approximation a disk of 30 mm diameter uniformly illuminated. The irradiation rate was varied from $1 \times 10^7\ p \cdot cm^{-2}$ to $2 \times 10^8\ p \cdot cm^{-2}$ according to our needs. DC-DC converters were mounted on jacks for vertical positioning and aligned with a laser alignment system. The samples were mounted perpendicular to the beam direction. During irradiation the converters were kept at a temperature of 32^oC. Typical power loads were 5% of the total capacity. Three parameters were monitored throughout the measurements: switching frequency, temperature, and output voltage.

Measurements with 300VDC

Three MINI converters were setup for irradiation with 300 VDC input voltage. In the first sample the beam was not centered on the power MOSFET but the MOSFET was still well within the illuminating disk. The second was irradiated under uncalibrated conditions. The third was irradiated with beam centered on the power MOSFET. All three samples failed. The failure cross section is approximately $\sigma_{fail} \sim 0.5 \times 10^{-10}\ cm^2$. This failure rate does not meet the design requirements and rules out the operation at 300 VDC.

Measurements with 200VDC

Two converters, one MINI and one MAXI, were irradiated with the input voltage reduced to 200 VDC. The beam in the case of the MINI was centered on the MOSFET and in the case of the MAXI centered between the two input MOSFETs. No failure was observed up to a total fluence of $2.18 \times 10^{11}\ p \cdot cm^{-2}$ in both cases. By de-rating the operating voltage the failure cross section is reduced. The measurements only allow to assign an upper limit of $\sigma_{fail} < 10^{-12}\ cm^2$. We have also irradiated the two control ASICs in the MAXI converter. Both were irradiated to $2.18 \times 10^{11}\ p \cdot cm^{-2}$. No failures were observed. A drift towards larger voltage output was seen during the irradiation of the output control ASIC. This appears to be consistent with previously seen behavior observed during gamma irradiation.

Conclusions

The failure is most likely due to a SEGR or SEB of the 600 V input MOSFET. The use of the Vicor DC-DC converter at its nominal input voltage of 300 VDC is not recommended. The option of de-rating the input voltage to 200 VDC should be carefully examined.